Prosthetics of the Future Will Mesh Body, Mind, Machine

Remember the 1970s TV show "The Six Million Dollar Man?" It featured a test pilot who suffered horrific injuries in a crash and was "rebuilt" with bionic parts. This made him a superman who could lift cars and leap 40 feet in the air.

The actual science of prosthetics has a more down-to-earth goal: to restore independence and mobility to amputees and enable them to do everyday things most of us take for granted—walking, running, enjoying hobbies, using a pen or fork, holding a child. But the technology emerging in labs today, including several VA sites, is no less dramatic than that depicted in the old TV show.

Take, for example, the work of Dr. John Donoghue at Brown University and VA's Center of Excellence for Rebuilding, Regenerating and Restoring Function after Limb Loss in Providence, R.I. Donoghue has developed a system called BrainGate that decodes brain waves—thoughts—and translates them into computer commands. Early results show that a quadriplegic can switch on lights and open e-mail using only his mind. The system, which uses a tiny sensor implanted in the part of the brain that controls movement, has huge implications for amputees. A person could simply "think" about moving his computerized artificial arm, and the thought could trigger the device to act.

The system still relies on wires hooked to the brain, but Donoghue's group and others pursuing similar work around the country plan to eventually have a wireless system. Dr. Richard Normann, the Utah bioengineer who developed the chip used by Donoghue, is spearheading a $6.7 million grant from the National Institutes of Health to refine the chip and explore further uses for it. "To go from a bundle of wires sticking out of somebody's head to a totally implantable system that is invisible will be a major advance in this technology," he says.

'Biohybrid limbs'

This research in "neuroprosthetics" is part of a larger trend in prosthetics that aims to integrate body, mind and machine. Dr. Roy Aaron, an orthopedic surgeon who directs the VA-Brown center, talks of "biohybrid limbs."

"Some breakthroughs may blur the distinction between biological and non-biological," says Aaron. His center, established by VA last year at the Providence VA Medical Center, is at the front edge of a movement to create prosthetic limbs that function almost like natural ones.

Dr. Roy Aaron directs a new limb-loss center at the Providence, R.I., VA Medical Center where scientists hope to create "biohybrid" limbs that will use regenerated tissue, lengthened bone, titanium prosthetics and implantable sensors that allow amputees to use nerves and brain signals to move arms or legs.

“These systems have to know how to walk,” says Herr. His latest knee-ankle prototype has sensors that measure force, position and movement and feed the data to an onboard microprocessor. The knee has an electromagnet and a friction-modulating fluid that changes in milliseconds from an oil to a near-solid in response to a magnetic field. The ankle may use polymers that turn electrical energy into mechanical force, thus acting as a sort of artificial muscle.

Herr envisions that in the future, “Amputees will be able to traverse greater distances with less fatigue. Artificial joints will be able to move like a biological joint.”

Two-way talk between brain, artificial limb

Herr’s model also uses “BIONs™,” short for bionic neurons. These microchips will be injected into residual leg muscles to pick up movement signals from the brain and send them to the artificial limb. Says Herr: “We need to have the amputee’s brain control the artificial knee, to tell the knee that they intend to turn left or right, or that there are stairs up ahead.”

BION technology, developed by the Alfred E. Mann Foundation, also figures in an artificial hand invented in the VA Chicago lab of Dr. Richard Weir. Sensors placed in existing arm muscles will pick up brain signals. An external controller will use “fuzzy logic”—the algebraic decision-making of artificial intelligence—to translate the signals into commands for the hand.

“We expect that for the first time in prosthetics history we will have enough control sites to do more than just open and close a hand—we should be able to control a wrist, a thumb, and possibly even individual fingers on a hand,” said Weir.

According to Dr. Danielle Kerkovich of VA’s Rehabilitation Research and Development Service, artificial hands of the future will also feature sensory feedback to the brain. “It won’t be just output—residual limb telling prosthesis what to do—but also prosthesis reporting back to the chip [and in turn, to the brain] what it did. So even if you weren’t looking at your hand, you could sense that it reached down and grabbed a can of soda.”

In fact, artificial hands of the future will likely contain not only sensors to monitor the force of a grip, but also hot and cold sensors that would even allow a user to safely prepare a baby’s bath.

Tissue engineering to complement robotics

Along with advances in engineering and robotics, cutting-edge medical techniques being explored at the new VA-Brown center promise to play a key role in 21st-century prosthetics:

• Surgical techniques to lengthen the bone in the residual limb will make it easier to fit artificial limbs and allow for greater control and mobility.
• Tissue engineering will help restore torn-up joints. Techniques could include the use of biodegradable polymer beads, smaller than a pinhead, which would release proteins to trigger the production of cartilage and possibly bone.
• Osseointegration—attaching prosthetic legs to a titanium bolt placed directly in the bone—may avoid some of the problems of current anchoring methods, such as skin sores, sweating and pain. Researchers in Providence, along with VA

colleagues in Salt Lake City and San Diego, are seeking ways to prevent the infections that often occur with the new method.

Artificial eye on the horizon

The same chip being used as an interface between brain and artificial limb may also help blind people see. Normann's group in Utah hopes to eventually implant his electrode array into the visual cortex, the part of the brain that processes visual information. Video signals from a miniature camera mounted in eyeglasses will travel through the electrodes and excite specific neurons, resulting in an image for the patient.

A different approach is being taken by Dr. Joseph Rizzo at the VA Center for Innovative Visual Rehabilitation in Boston. His model is an artificial retina, designed to help patients with macular degeneration or retinitis pigmentosa. The system bypasses damaged photoreceptors—rods and cones—and electrically stimulates the remaining healthy cells of the retina. Like other prosthetic prototypes, it relies on electrodes and a chip to bridge the gap between body and machine.

Many other groups around the United States and Europe are working on artificial eyes, with some experts even predicting a product on the market by 2010.

But as with all medical technology, bringing a product from bench to bedside is a chief milestone but not the end of the story. Researchers have to make sure the device works in the real world.

Good examples are studies by Dr. Joseph Czerniecki at VA's Center for Limb Loss Prevention and Prosthetic Engineering in Seattle, and Dr. Steven Gard at the VA Chicago's Motion Analysis and Research Laboratory. These researchers are conducting some of the first rigorous trials of the C-Leg, the current state-of-the art computerized knee that has been fitted on many Iraq veterans. The leg, which costs more than $40,000, seems popular with amputees, but scant clinical evidence exists to back its claims of easier walking.

Amputee care: Lessons learned from Iraq

No less important than new gadgetry is the care amputees receive during rehabilitation. Here too, the model is changing from what it was in previous eras.

"One of the biggest things we're learning in the psychosocial arena from the men and women coming back from Iraq is that their going through this together is helping them enormously," says Kerkovich. She cites the unique support system at Walter Reed Army Medical Center, where most new amputees are receiving long-term therapy, and points out that VA is developing special video games for upper-limb amputees at the Army facility to help them learn to use their prosthetic arms.

Recently at Walter Reed, VA investigator Dr. Robert Gailey and a group of Paralympic athletes held a weeklong clinic to teach new artificial leg users how to run.

"Years ago, that wouldn't have happened," says Kerkovich. "Amputees were taught how to walk, and that was it. It shows how rehabilitation has advanced—we're getting better at figuring out that maybe patients can get better months, even years, after the injury, if we keep at it."

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